THE FUTURE OF NUCLEAR ENERGY

Dr. J. I. Sackett
Argonne National Laboratory
P.O. Box 2528
Idaho Falls, ID 83403-2528

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A PERSPECTIVE ON NUCLEAR POWER DEVELOPMENT

Nuclear power started with the discoveries before and during World War II, a remarkable time in our history. The defining event took place at the University of Chicago on December 2, 1942 when it was demonstrated that nuclear fission could be sustained and controlled. This ushered in the nuclear age.

Following World War II, the United States government and the University of Chicago organized Argonne National Laboratory (ANL) to continue research into peaceful uses of this awesome power. Soon there was need for a site that could host the construction of experimental nuclear power plants. Idaho was chosen by then Argonne director Walter Zinn. It led to the construction of the Experimental Breeder Reactor I (EBR-I), the first reactor to produce electricity, and the boiling water reactor (BORAX), which tied into the grid and made Arco, Idaho the first town in the world to be lit with nuclear energy. From this simple beginning – a string of eight dim light bulbs and four hours of power to a small desert town – nuclear power has grown to account for about 17% of energy production world wide with more than 400 plants in operation. In the United States, there are more than 100 plants in operation, accounting for slightly less than 20% of our electric power production. It is important that even though there have been no new nuclear plants built in the last 15 years, we as a nation have been able to meet our growth in electric energy consumption primarily because of improvements in the efficiency and reliability of operation of nuclear power plants. They are now on-line, producing power, close to 90% of the time. The point is that despite all of the negative press, commercial reactors are operating very well and are an important part of our energy mix.

These reactor designs currently in use evolved from work primarily associated with what was done by the Navy. Westinghouse was a major contractor for the Navy, developing the pressurized water reactor that represents most of the plants in operation in the United States today. There are a few boiling water reactor designs, developed by General Electric, but they are in the minority. Sodium cooled reactors, such as EBR-I which besides producing the first electricity could create more fuel than it burned, never caught on. Water-cooled reactors were preferred by the Navy, so they got a leg up in the early days. There is a mature technology with these plants, there is not a shortage of fuel, and the technology has been deployed world wide. Water-cooled reactors do, however, create a great deal of spent fuel that we are just now beginning to grapple with. As the needs grow, different designs will take their place.

There are other designs scattered around the world, such as the Chernobyl type reactors that are a derivative from the Russian weapons program. Gas-cooled reactors operate in a few places. And there are a few operating sodium cooled reactors of a type that when eventually deployed, can greatly extend the available fuel supply.

It is worth commenting that many nuclear plants are becoming hugely profitable in the United States, primarily because they are becoming available at fire-sale prices. At least two operating companies have organized to buy them and operate them. The operating reactor at Three Mile Island (TMI) is a case in point. It cost several billion to construct, but was sold for about $30 million to a company called PepCo, a very competent operator of nuclear plants. We will see much more of this as individual utilities go out of the business and operating companies begin to take over, largely a result of deregulation of the electrical power industry. Many of the problems we know today developed because in the early history of nuclear power it was very fashionable for individual utilities to own a nuclear power plant, and many got into the business without the technical and management expertise to build and operate them. Witness the WPSS plants on the Columbia river in Washington state. This problem is now sorting itself out.

All of this experience, positive and negative, is laying the basis for what nuclear power will become. The future will be different than what we see today.

The world's population has reached 6 billion people and is projected to reach 10 billion in the next century. More than 30% live in poverty without access to electricity. Their life span averages less that 40 years. With access to even a little electricity and the benefits it brings, life span increases dramatically, to about 65 years. Significantly, the quality of life also increases dramatically.

Deregulation is spurring much innovation in the power generation business favoring small distributed generating sources that may well be suitable for many of these developing nations in the beginning of their expansion. Natural gas will grow in importance, particularly in the United States. But many countries either don't have access to gas, or the infrastructure to support it, or both. Electricity can be produced by many means, but only nuclear, coal and natural gas together have the potential to meet the needs of the next century, driven by the rapid growth of developing countries. To keep up, electricity production is expected to triple by the middle of the next century.

Some would say that we can't afford such growth. However, we cannot deny to the growing population of the world the benefits of a high standard of living. Just as important, it has been demonstrated over and over again, that countries with high standards of living have low population growth and less environmental degradation. So, besides improving the lives of individual people, such economic growth can also benefit the globe environmentally. That is really the key question, can we manage energy growth in a way that we can meet the needs of a hungry world, stabilize economics and protect the environment. This is a challenge worthy of us all.

Coal, in its present, cannot be a major part of that solution for a simple reason, global warming. The science to predict effects of CO_2 emission is still immature, and there is much uncertainty, but if the predictions are correct, it will have profound effects on climate, even at current levels of emissions. There is now no real question that global temperatures are increasing and that we will see the effects of human activity on global climate. What those affects will be and what to do about them are the present questions. There is talk of CO_2 sequestering but it is a technology far off. Natural gas can help, but only to a certain extent. We can talk about energy conservation, but that is for the developed nations, not the developing nations. We can talk about new technologies, solar, biomass, etc., and they have their place, but they will play only a part.

In spite of all its benefits, it is very unlikely that nuclear can fill the gap by itself, even if it is fully embraced. The required growth is phenomenal. For nuclear to provide even one-third of the carbon-free energy supply necessary to stabilize CO_2 levels would require building the equivalent of 100 large plants per year, starting now. If nuclear power is to play an essential part in addressing the greenhouse problem, slow steady growth will not be enough.

THE CHALLENGES FOR NUCLEAR POWER

Proliferation of Weapons Material

The first challenge for substantial growth of nuclear power is to prevent the proliferation of material that could be diverted to use in nuclear weapons. This is probably the greatest and most reasonable fear of those who strongly oppose nuclear power, especially its use in developing countries. It is such an emotional issue that there is talk about putting the genie back in the bottle. The nuclear genie cannot be put back into the bottle, so we will have to learn to control it. Nuclear has immense capability for good or for destruction. Frankly, our present problem is that nuclear power grew out of the weapons programs of Russia and the United States and we have ended up with technologies that are closely linked. We can do better. The first step is to bum down, to destroy, and to eliminate the excess weapons material that we currently have available. Burying it is not good enough. Let me say that again: burying it is not good enough. What we are talking about is not just the material produced for the weapons program, but the greater quantity of separated material produced in the civilian nuclear power programs. Burning the inventories down will greatly assist in management of the material that remains. Simply speaking, if the remaining material is locked up in reactor systems, it can't be used for weapons. Even more importantly, it can easily be monitored. What we need are reactor systems and associated fuel cycles that make it extremely difficult or impossible to divert material to weapons use. And we need the monitoring systems to make any attempt at diversion obvious to all.

Waste Management

Waste management is also an issue dominated by emotional considerations. The fundamental difficulty, as I have said, is that we are presently hung up on putting the genie back into the bottle. To this end, the permanent repository at Yucca Mountain in Nevada is intended to permanently lock material away, for a million years or more. This approach, of course, is hugely wasteful of a tremendously valuable resource, and probably can't be done to the standards being imposed anyway. Others outside our disciplines are beginning to understand this. There is currently an intense debate in Congress over employing interim storage instead of permanent disposal and transmutation of the waste, using reactors or accelerators is also being considered. There are international studies looking at the same questions. There are also international studies looking at improved methods of fuel management that include recycle. One thing is clear, burning less than 1% of the available fuel and discarding the rest as we are doing today is bound to create a huge waste problem. It is simply better to recycle, as we do with so many of our other products. This will come. It is a question of time and the right technology. I would emphasize that it is recycle for the purpose of burning down the inventory of material, not creating more. To this end, the Russians and the Japanese are entering into an agreement for fueling a Russian sodium-cooled reactor with weapons plutonium, recycling the fuel in a proliferation resistant system using electrorefining. We can expect other international initiatives to develop, such as deep burn reactors and other concepts. We also should be exploring long life reactor cores that produce and burn their own fuel without need for external separation of material.

Economics

Any power source must make sense in a competitive market. Nuclear power suffers from the fact that each plant built in this country was one of a kind, with only a few exceptions. Further, each one had to be a Cadillac to satisfy safety requirements, requirements which were continually being changed.

The automobile industry could not succeed on a broad scale until it moved away from hand building individual luxury cars and moved toward mass production of vehicles that comply with known and excepted standards. The same applies to nuclear plants. The cars of today are vastly superior in every respect, especially safety, to those that preceded them, hand built or not. They are a great value.

The same must happen with nuclear power. Smaller, modular plants produced in factories are part of the answer. Standardization of a few designs is another part of the answer. Surprisingly, cheaper and simpler can also mean safer.

Safety

The enemy of safety is complexity. Our nuclear plants have become increasingly complex, in part, ironically, because of the addition of many safety systems. It is always more straightforward to engineer a safety fix with the addition of a new system. Rather, I think we need to return to the fundamental design and take advantage of the inherent physics to ensure that it will respond safely. It is possible to design an aircraft that can glide after the engines are lost, and to stall at such a slow speed that it can be landed safely on rough terrain. Likewise, it is possible to design a reactor that will coast down in power on its own after losing all electrical power, without requiring active safety systems. This concept was proved at Argonne in 1986 when all safety systems and cooling systems were disabled at full power on EBR-II. Because this reactor employed inherent safety in its design, it coasted down safely and never over heated. Such features are being incorporated into the newest designs. Unfortunately, they are not being built in this country so we cannot directly see their benefits. One huge benefit is that their safety systems can then be simplified, and costs reduced. This is a field of research and development with great promise for the future.

Perhaps, though, the biggest challenge in the meantime is avoiding accidents. Another accident on the scale of Chernobyl, or continuing accidents like the criticality in Japan, would have a devastating impact on the nuclear industry. Yet today, there are 26 of the oldest Soviet designed power plants in operation; 14 of the RBMks and a dozen of the VVER-440-230s. They have no containment vessels and inadequate to non-existent emergency core cooling systems. Genuine safety risks exist elsewhere where rapid growth is foreseen without the infrastructure to support it. The United States must provide the leadership to ensure that these problems are addressed.

THE FUTURE FOR NUCLEAR POWER

Advanced Reactor Development

We are then confronted with the challenges of proliferation, waste, economics and safety. These are not new challenges. We addressed them at Argonne in the early 80s with the development of the Integral Fast Reactor (IFR) program, and created a great deal of excitement in the process. We demonstrated that a proliferation resistant fuel cycle, that is transparent for those who would monitor it, could be developed. We demonstrated that fuel could be recycled to the reactor, so that fuel and fission products could be burned, not added to the waste and buried. We demonstrated that we could simplify the design, greatly improving the economics. And we demonstrated that safety could be assured while greatly simplifying reactor design. In short, the IFR program was a great technical success. It made significant progress in both defining the questions to be asked, and in answering them. Even though the IFR was terminated for political reasons in 1994, it has laid the groundwork for important work in the future. Much of this work is happening in the international arena.

There is much being done in the international arena. Unfortunately, much of it has to do with correcting the mistakes of the past, cleaning up contamination from many sites associated with the weapons programs and properly managing material and reactors that remain.

It is important that the United States maintain its expertise if it is to maintain international leadership. Problems will arise and it is important that we are able to deal with them. Developing nations will turn to nuclear power to improve the lives of their people, and it is important that we are at the table to assure that this is done in a safe and secure manner. The only way for other nations to respect the United States as a leader in policy is to be a leader in the technology.

Fortunately, there are important initiatives emerging. Congress has funded the Nuclear Engineering Research Institute (NERI) at $19 million, a relatively low level, but an important beginning. The money funds a number of nascent, innovative research initiatives from universities and national laboratories to develop new approaches to nuclear reactor design, among other things. Let me describe one such initiative. There is being developed a water-cooled reactor with a core that is envisioned to operate for 14 years without refueling. At 14 years, the whole core will be replaced. Because there is no need for refueling, there is no need for a refueling system and the cost it entails. Because there is no movement of fuel, there is no risk of diversion of material.

In addition, the design will maximize thc inherently safe response to upsets. For example, the core can be cooled by natural convection only, without need for pumps or electric power. Such simplification can enhance safcty and reduce cost.

Probably the best demonstration of what can be achieved was with the sodium cooled reactor, EBR-II. In 1986, two landmark demonstration tests were conducted before an international audience. The reactor was subjected to the two worst events that can befall a power reactor.

In the first, the reactor was brought to full power, the automatic shutdown system was disabled and all electric power to the reactor cooling systems was removed. The coolant flow to the core immediately began to decrease, the reactor temperature started to rise, but instead of melting the core, it shut itself down without damage. It glided to a safe landing where it remained.

In the second test, the reactor was again brought to full power, the automatic shutdown system was disengaged and all power was cut to the pumps that reject heat from the reactor. The response was even more benign in this test than in the first. Again, the reactor shut itself down with no damage.

Such designs are possible and have captured the imagination of an international audience. In the example mentioned for a light water reactor design, the French and the Japanese are participating. Another reactor design, a pebble-bed gas cooled reactor, has attracted an even broader international audience.

CONCLUSION

We can all be thankful for nuclear power, for it may well be essential to the long term survival of civilization. Within the seeds of its potential for great good, are also the seeds for great harm. We must ensure that it is applied for great good. What is not in question is whether we can live without it, we cannot.

United States leadership is crucial in determining how this technology is developed and applied. The size and capability of the United States technical community is decreasing, a trend that cannot be allowed to continue. It is my belief that in the future, the need, the vision and the confidence in nuclear power will be restored, but only if we address the immediate challenges before us. It is a national challenge worthy of the best people this nation has to offer.